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Color specification for color rendering

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***Abstract* – The present work was carried out as part of the CLEAR project, which aims to create a virtual diagnostic laboratory for polychrome artifacts through the definition of an image acquisition and processing protocol with high resolution and accuracy in terms of colour rendering. To achieve this goal, contact spectrophotometric and distance spectroradiometric measurements for colour specification will be performed. All data will be used for the processing, training, and validation of a predictive model for the evaluation of colour differences and for the creation of a two-way correspondence between RGB colour values and coordinates expressed in the CIELAB colour space. On this occasion, the results obtained on a first series of laboratory specimens consisting of monochrome cubes to highlight the influence of the contact and distance measurements on the calculation of the RGB triplet are discussed.**

I. INTRODUCTION

Color is an essential characteristic of works of art and most diagnostic projects are aimed at assessing it both to check its stability over time and for its accurate reproduction in restoration work, in prints and on video.

An ideal conservation program involves color measurements at predetermined time intervals, while in restoration projects, measurements are taken before and after each intervention. The accuracy of colour rendering in digital images is of considerable importance in the fruition of cultural heritage. It is essential that the images disseminated through websites and web platforms, as well as the ones used for the realization of virtual tours, render the colour of the works as closely as possible to that perceived by the viewers in presence.

The reliable reproduction of colour in images of polychrome artefacts is also important in the field of archaeometry. For example, data obtained from colorimetric analyses has been used to improve colour rendering in images of archaeological pottery which were later used to specify the colour objectively [1-4].

Colour is a sensation and as such it is a subjective and incommunicable quantity. Colour measurement is possible because we can create a correspondence between colour perceptions and the light radiations that stimulate them. This concerns the physics of light radiation, the physiology of the visual process and the psychology of vision. Starting from the optical properties of a coloured object, and the spectral reflectance factor, it is possible to specify the colour. That is, the association of a tern of values that identify the brightness, hue and saturation of the perceived colour. The values depend on the emission spectrum of the light source, the illumination and detection geometry and are related to the response of the human eye [5].

The Commission Internationale de l'Eclairage (CIE) has defined various spaces for measuring colour, including the CIELAB, considered approximately uniform and useful for comparisons of colour differences between object colours of same size and shape. The tern (L*, a*, b*) with the chromatic coordinates lightness (L*), green-red (a*) and blue-yellow (b*) components is the result of color specification [6]. For color measurements we chose the CIELAB 1976 color space that is one of the most used for communicating and expressing color in the research field considered. Furthermore, the CIELAB color space was designed to be perceptually uniform with respect to human color vision, which means that the same amount of numerical variation corresponds to approximately the same amount of change perceived visually [7].

The Color Model most used in digital image processing is the additive RGB color space. A specific RGB color space is defined by the three chromaticities of the red, green and blue primaries, which define the gamut of the color space. RGB is a device-dependent color model: different devices detect or reproduce a given RGB value differently, since the color elements (such as phosphors or dyes) and their response to the individual red, green, and blue levels vary from manufacturer to manufacturer, or even in the same device over time. Thus, an RGB value does not define the same color across devices without some kind of color management [8].

The main objective of the research program in which this paper is included is to obtain RGB images where the colour rendering is accurate. In this context, the image of an artwork is considered reliable when it is chromatically faithful to the perceived colour. The concept of accuracy relates to the difference between an expected value and the value considered true. In this context, a colorimetric triad in RGB space is considered accurate when values close to those obtained from colour measurements using CIELAB space are obtained. The results obtained on a first series of laboratory test samples, consisting of monochromatic cubes, are discussed, comparing the chromaticity coordinates acquired with a 3D scanner with those obtained from measurements performed with both the contact spectrophotometric and the distance spectroradiometric methods. This is a methodological study aimed at quantifying the influence of the colour measurement method, used as a reference for colour specification, on the colour rendering of digital images.

Contact colour measurements are generally considered more reliable since they are not affected by influences and interferences as in the case of distance measurements. In the latter case, there is less control over the acquisition and detection geometry, the light source is external, and the measurement area is not accurately identified. However, they are the only possibility in the case of precious or hard-to-reach artefacts such as frescoes and wall paintings.

II. MATERIALS AND METHODS

The measurements were conducted on 7 monochromatic cardboard cubes with a 7 cm side belonging to a set consisting of 50 cubes of different colours in terms of hue, brightness and saturation. In particular, the black (K), white (W), red (R), green (G), blue (B), yellow (Y) and grey (Gy) cubes were the focus of this study (Figure 1).

The choice of these colors to be measured was made on the basis of the four hues (red, green, yellow and blue) identified in the x- and y-axes used to represent the a* and b* color coordinates of CIELAB space, the minimum value (black), maximum value (white) and one among them included (gray) of the z-axis relative to the L* coordinate.

Contact color measurements were conducted using a Konica Minolta model CM-2600d spectrophotometer. The measurement geometry is d/8°, Ø = 6 mm (SAV, Small Average Value) was selected and the chromatic coordinates are related to the D65 illuminant and the CIE 1964 standard colorimetric observer (10° standard observer). The scale adjustment was performed using the white calibration plate (CM- A145) and the black box (CM-A32) as the target for, respectively, the maximum and the minimum lightness value [8]. Data elaboration regarded SPEX/100 values (SPecular component EXcluded and UV included) and was performed by a dedicated software (SpectraMagic®). Color measurements at distance were conducted using Konica Minolta Spectroradiometer CS1000A with solid angle of detection of 1°. The object-detector distance was of 50 cm and the measurement geometry was 45°/0°/45°. A white calibration standard (CS-A5 13871004) was used as the maximum lightness reference. The color coordinates corresponding to the 10° observer and the D65 illuminant were taken into account through the CS-S1w software.

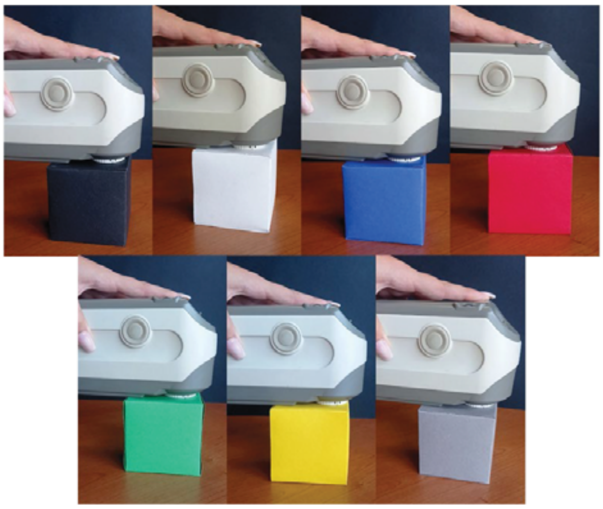

Fig.1 Sample objects of the study: black (K), white (W), blue (B), red (R), green (G), yellow (Y) and grey (Gy) hue cubes. In the picture the spectrophotometer used for at contact measurements is shown.

To acquire the 3D models and the textures of the cubes, a Konika Minolta VI-9i with a 14 mm focal lens and a resolution of is 640x480px was used. The cubes were placed inside a Color Assessment Cabinet (CAC) selecting the D65 simulator (Figure 2). In order to estimate the 3D scanner color rendering, a region of interest (ROI) of 5x5 pixels was selected inside the images and the mean value for each R, G and B channel was calculated. Finally, the RGB to CIELab color transformation was performed using the python image processing toolbox scikit-image, the formula conversion parameters were set using the D65 as the reference illuminant and 10 degrees as the aperture angle of the observer (as performed in distance and contact measurements) [10,11].

Fig.2 Set-up for 3D acquisitions.

To quantify differences between data obtained with different methods, the ΔE*ab parameter was used and calculated with the following equation [5, 11]:

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}.$$

This approach, which originated for the purposes of quality control in industry, assumes that there is a reference color (target) against which to compare a test sample.

In the present work the differences between colorimetric measurements performed by the contact spectrophotometric method and the distance spectroradiometric method, considering the first as target, were evaluated in a first step.

In a second step, the calculation of the DE parameter was carried out by considering the contact-measured and the distance-measured chromaticity coordinates as targets, respectively, and the CIELAB chromaticity coordinates calculated from the values of the RGB terns derived from the 3 D scanner images as samples.

As usual, the values obtained for color differences will be considered on the assumption that a DE of 1.0 is the smallest color difference that the human eye can see. Thus, any DE less than 1.0 is imperceptible while any DE greater than 1.0 is considered perceptible.

In the evaluation of color differences, in addition to the concept of difference, the concept of tolerance is also considered. In CIELAB space if difference is a number indicating the distance between two colors, tolerance is the meaning of the number contextualized for the case under consideration. In the field of digital images, setting a tolerance level, such as 2 in CIELAB space (2.0 dE76), defines what is accepted and what is rejected by comparing a reference image with a reproduced image (reproduction tolerance).

III. RESULTS AND DISCUSSION

Considering the at contact spectrophotometric color data as the target, the difference between the latter values and the color specification obtained through at distance spectroradiometric method was calculated. Considering each coordinate, the values of ΔL*, Δa*, and Δb* were listed in the Table 1 together with the related ΔE values.

Table 1. Colorimetric differences between at contact and at distance measurements.

Color	ΔL*	Δa*	Δb*	ΔE
K	-0.14	-0.26	0.88	0.93
W	0.08	-1.27	5.36	5.51
R	-0.01	0.94	-0.38	1.01
G	0.26	2.16	0.09	2.18
B	-1.56	-0.17	1.63	2.26
Y	-1.09	2.16	0.80	2.55
Gy	-0.50	-0.61	0.26	0.84

The ΔE values show good agreement, both considering the maximum value of the parameter to be 1 and referring to a tolerance equal to 2. The only exceptions are the values of the measured colour coordinates for white for which an appreciable colour difference was found (E > 5). This deviation is most certainly due to the different procedure for the adjustment of the lightness scale and, above all, because no reference for black is used for the at distance measurements [9].

The representation of the differences between the color coordinates (Figure 3) shows that the white measured with the spectroradiometer shifts towards a greater yellow component while yellow and green shift towards a greater red component. The other hues, considering the experimental uncertainties, do not undergo significant shifts.

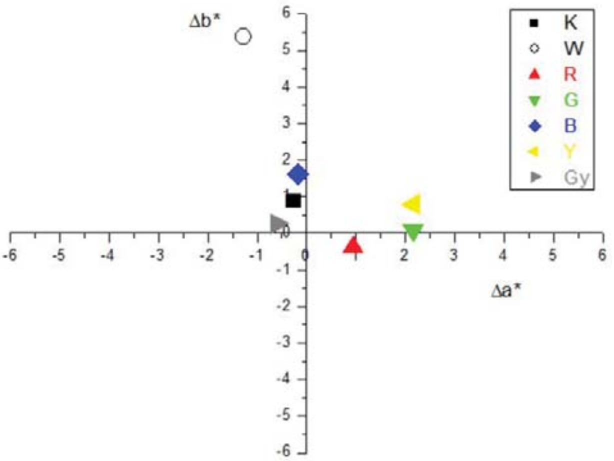

Fig.3 Differences between a and b* coordinates calculated considering values obtained with spectrophotometer and by spectroradiometer, respectively, as target and sample.*

The colour differences between the colours of the images acquired with the scanner and those measured with the contact and distance methodologies were calculated considering the CIELAB space.

The ΔE parameter obtained with the 3D scanner coordinates and those obtained with the spectrophotometer and spectroradiometer, respectively, are shown in Table 3.

ΔE	**3D/contact**	**3D/distance**
K	20.07	20.10
W	60.79	62.93
R	32.50	32.94
G	52.78	51.85
B	69.28	69.05
Y	29.30	27.93
Gy	35.47	35.31

IV. CONCLUSIONS

The results obtained show that the values measured with both at contact and at distance methodologies can be used to optimise colour rendering in 3D images. The differences between the coordinates of the 3D images and the measured ones are very high in terms of ΔE but still comparable. With the aim to reduce these differences, a new measurement campaign is scheduled to be conducted using 3D acquisitions with scenes that include the white references of both experimental methodologies.

Data processing will also be carried out by considering the differences between the individual coordinates L*, a* and b* in order to highlight if different hues show different trends

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